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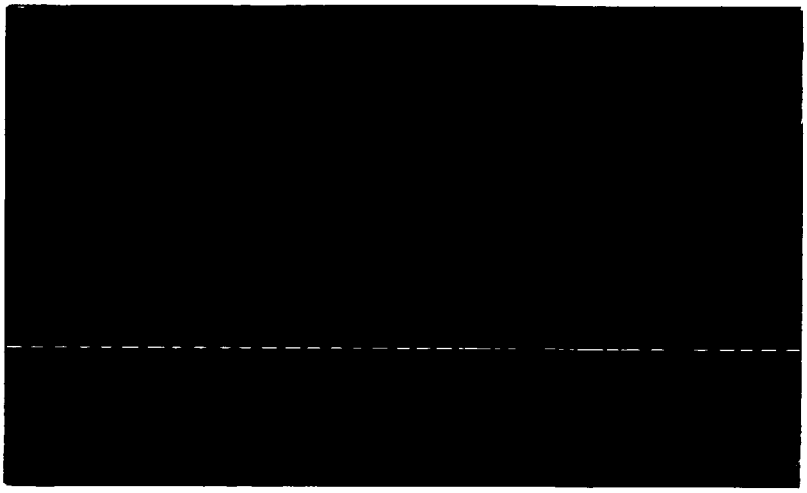

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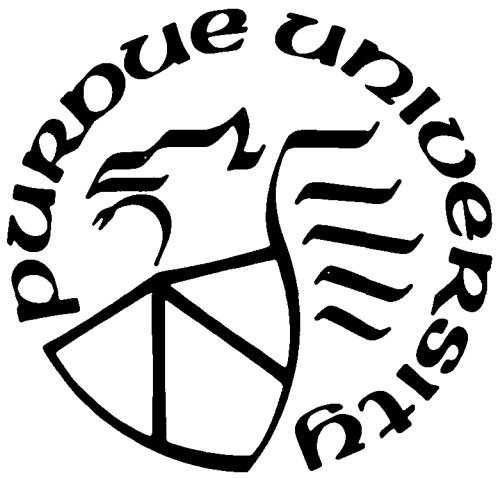

Lafayette, Indiana 47907

SOURCE ENCODING FOR 2-DIMENSIONAL DATA
FINAL REPORT ON RESEARCH PERFORMED UNDER NASA GRANT NGR 15-005-106

by

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Technical Report No. TR-EE 73-11
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This report summarizes the work performed under NASA Grant NGR 15-005-106 from July 1, 1969 to July 1, 1972. An extension to December 31, 1972 was granted to allow for the preparation of the final report. This final report consists of the papers, technical reports, etc. that resulted from this research program. The papers are listed in inverse chronological order.

The research performed under this NASA Grant resulted in the publication of one book chapter, twelve articles published in the IEEE Transactions and the Proceedings of IEEE, eight conference papers, and eight technical reports. The paper "Transform Picture Coding", listed as No. 8 in this report, won the IEEE Communications Society 1972 Leonard G. Abraham Prize Paper Award for being the best paper to appear in the IEEE Transactions on Communications during 1971.

This NASA Grant provided financial support for seven Ph.D. students and one M.S. student.

1. Title: The Effects of Channel Errors in DPCM Systems and Comparison with PCM Systems
Author(s): P. A. Wintz and J. E. Essman
Where Appeared: IEEE Trans. on Communications, (Accepted for publication, but not yet in print).

ABSTRACT

In a communications system the total system error is of importance. One measure of system error is the mean square error between the input signal and the output signal. The total mean-squared error includes sampling error, quantization error and channel error.

The work reported here considers all three errors in Differential Pulse Code Modulation (DPCM) systems and compares the results obtained with standard Pulse Code Modulation systems (PCM). The total mean-squared error is determined using well defined system parameters such as quantizer levels, signal-to-noise ratio (SNR), sampling rate, etc. Using the derived formulae the design of DPCM systems is facilitated along with various tradeoff studies. The error equations are determined for both uniform and nonuniform quantizers. The error due to channel noise is obtained in closed form for both cases.

DPCM and PCM are compared for three different reconstruction filters, the zero-order-hold (ZOH), the linear interpolator (LI), and the zero-order-hold followed by a low pass filter. The optimum prediction coefficient is shown to depend on the channel noise. The optimum prediction coefficient improves the performance of a DPCM systems considerably. DPCM is shown to perform superior to PCM in all cases. Simulation results are presented which verify the theoretical results.

2. Title: Note on the Error Signal of Block Quantizers
Author(s): P. A. Wintz and M. Tasto
Where Appeared: IEEE Trans. on Communications, Vol. COM-21, No. 3, March 1973.

ABSTRACT

We show that the error signal incurred by block quantizing stationary data is nonstationary under some conditions. Examples are presented that indicate that the mean square error is largest at the block edges. When block quantizers are used to encode pictures at low bit rates, this effect tends to make the block edges visible in the reconstructed picture.

3. Title: Subjectively Relevant Error Criteria for Pictorial Data Processing
Author(s): P. A. Wintz and W. C. Wilder
Where Appeared: TR-EE 72-34, School of Electrical Engineering, Purdue University, West Lafayette, Indiana, December 1972.

ABSTRACT

Subjectively relevant error criteria for picture processing are sought from the viewpoints of overall detail quality and overall quality, reflecting the needs of a technical observer and a recreational viewer, respectively. Category testing is employed to subjectively evaluate sixteen processed pictures of each of three scenes according to each of these two quality viewpoints. The pictures represent the effects of four different processing methods.

Fifteen objective error measures are calculated on a point-by-point basis between the original and each processed picture. These are compared with the results of the subjective tests to determine which, if any, are highly correlated.

Comparing the subjective evaluations according to overall detail quality with the fifteen error measures averaged over the entire picture resulted in laplacian errors having the highest degree of correlation and the gradient errors exhibited positive correlation over all three scenes, with the laplacian errors having a higher degree of correlation.

Further subdivision of the fifteen error measures provided no more conclusive result but suggested that error measures which take area, rather than point, properties into account appear more subjectively relevant.

4. Title: The Effects of Channel Errors in DPCM Systems
Author(s): P. A. Wintz and J. E. Essman
Where Appeared: Proc. of the 1972 Computer Image Processing and Recognition Symposium, Columbia Missouri, August 1972.

5. Title: Transform Coding
Author: P. A. Wintz
Where Appeared: Presented at University of Utah, August 1972.

6. Title: Computer Analysis of X-Ray Images
Author(s): P. A. Wintz and A. Kak
Where Appeared: Presented at Regenstrief Institute Seminar, Indiana University Medical Center, Indianapolis, Indiana, July 1972.

7. Title: Theory and Application of DPCM and Comparison of DPCM with other than Predictive Techniques
Author(s): P. A. Wintz and J. E. Essman
Where Appeared: TR-EE 72-22, School of Electrical Engineering, Purdue University, West Lafayette, Indiana, July 1972.

ABSTRACT

Differential pulse code modulation systems are analyzed using total mean-squared error as the measure of fidelity. The formulation of the total system error is done using sampled data and spectral techniques. Design formulae are obtained in terms of tangible system parameters such as sampling rates, quantizer levels, quantizer ranges, signal-to-noise, etc. The use of uniform and nonuniform quantization are considered. The formulae derived include the effects of channel errors when nonuniform quantization is used. Spectral densities for the various error terms in DPCM are obtained. The effects of channel errors using nonuniform quantizers are shown to result in an error spectral density which is not white. This result indicates the propogation of error in DPCM systems. Approximate results for the spectral density of the error term due to channel noise are obtained which is valid for a three or more bit quantizer. Simulation studies are performed to justify the assumptions of independence between the quantizing noise and the input signal; between the channel noise and the input signal; and between the channel noise and the quantizing noise.

The derived formulae are used to obtain the total system error using three reconstruction filters-the zero-order-hold, the linear interpolator, and a zero-order-hold followed by a low pass filter. The optimum prediction coefficient is obtained for each reconstructor for both the noiseless case and noisy case. For the noiseless case the optimum prediction coefficient is that prescribed by prediction theory. For the noisy case the optimum prediction coefficient differs from that prescribed by prediction theory depending on the signal-to-noise ratio. Rate distortion curves are presented for PCM and DPCM using the various reconstruction filters. The use of the optimum prediction coefficient in the noisy case results in the occurrence of the knee of the rate distortion curves at higher bit rates and lower error. Results are presented in terms of the bit savings obtained in using DPCM over PCM for equivalent

performance of the two systems. In all cases it is seen that the performance of DPCM is superior to that of PCM. Simulation results are given for PCM and DPCM which verify the theoretical results.

DPCM techniques are used to process still pictures consisting of scenes of a cameraman, a face, a crowd, a chest X-ray and an X-ray of a skull. Results are presented for various error criteria and for various number of quantizer levels. It is seen that three bits are sufficient for a good reproduction. Two bits appear to give usable results, particularly for the medical pictures. The effects of channel noise and using too high of a prediction coefficient are shown for the scene of the cameraman.

The results of processing the various pictures by the Zero-Order-Predictor method (ZOP) and the Fan method are given. Since these methods require a buffer for temporary storage, experimental results are given to determine the optimum length of the timing word. The effects of channel noise, buffer underflows and buffer overflows are indicated for the scene of the cameraman. These types of predictive techniques are very sensitive to channel noise. The results of using the Fan method and the Zero-Order-Predictor method appear to be approximately equivalent. The primary degradation in both systems is due to streaking. This is less noticable in the Fan method.

Comparisons between the pictures obtained using the Fan and ZOP methods with those obtained using DPCM indicate that DPCM can be transmitted with over one bit per picture element less. The pictures of the skull and the chest using DPCM techniques are of considerably higher quality than those obtained using the ZOP and Fan methods. For these pictures, two bits per picture element gives satisfactory results using DPCM techniques. The Fan and ZOP methods require over four bits per picture element to obtain usable results.

8. Title: Transform Picture Coding
Author: P. A. Wintz
Where Appeared: Proc. IEEE, special issue on digital picture processing, Vol. 60, No. 7, July 1972.

ABSTRACT

Picture coding by first dividing the picture into subpictures and then performing a linear transformation on each subpicture and quantizing and coding the resulting coefficients is introduced from a heuristic point of view. Various transformation, quantization, and coding strategies are discussed. A survey of all known applications of these techniques to monochromatic image coding is presented along with a summary of the dependence of performance on the basic system parameters and some conclusions.

9. Title: Image Coding
Author: P. A. Wintz
Where Appeared: Presented at Workshop on Medical Image Processing, University of Notre Dame, Notre Dame, Indiana, May 1972.

10. Title: Estimation of Correlation Functions by Stochastic Approximation
Author(s): P. A. Wintz and A. Habibi
Where Appeared: IEEE Trans. on Aerospace Electronic Systems, Vol. AES-8, No. 3, May 1972.

ABSTRACT

Two techniques for estimating the correlation function of a stationary random process using the method of stochastic approximation are developed. Both provide updated estimates as successive T second observations are processed. Both assume a functional form for the correlation function that depends on a number of parameters that are estimated. One technique is based on the mean square error, and the other maximizes a likelihood function. Examples are included.

11. Title: Multispectral Data Compression Through Transform Coding and Block Quantization
Author(s): P. A. Wintz and P. J. Ready
Where Appeared: TR-EE 72-2, School of Electrical Engineering, Purdue University, West Lafayette, Indiana, May 1972.

ABSTRACT

Transform coding and block quantization techniques are applied to multispectral data for data compression purposes. Two types of multispectral data are considered, (1) aircraft scanner data, and (2) digitized satellite imagery. The multispectral source is defined and an appropriate mathematical model proposed.

Two error criteria are used to evaluate the performance of the transform encoder. The first is the mean square error between the original and reconstructed data sets. The second is the performance of a computer implemented classification algorithm over the reconstructed data set. The total mean square error for the multispectral vector source is shown to be the sum of the sampling (truncation) and quantization error.

The Karhunen-Loeve, Fourier, and Hadamard encoders are considered and are compared to the rate distortion function for the equivalent gaussian source and to the performance of the single PCM encoder.

The K-dimensional linear transformation is shown to be representable by a single equivalent matrix multiplication of the re-ordered source output tensor. Consequences of this result relative to the K-dimensional Fourier and Hadamard transformations are presented.

Minimization of the total encoder system error over the number of retained transform coefficients and corresponding bit distribution for a fixed data rate and block size is considered and an approximate solution proposed. Minimization of the sampling error over the data block size for the continuous source is also considered.

The results of the total encoder system error problem are applied to both an artifically generated Markov source and to the actual multispectral data sets.

The Karhunen-Loeve transformation is applied to the spectral dimension of the multispectral source and the resulting principal components are evaluated as feature vectors for use in data classification.

Experimental results using the transform encoder and several different (i.e., one, two, and three dimensional) data blocks are presented for both the satellite and aircraft data sets. Performances of the encoders over the three test regions within the satellite data are evaluated and compared.

12. Title: Transform Coding of Images
Author: P. A. Wintz
Where Appeared: Presented at the Conference on 'Digital Processing of Signals in Communications' in England, April 1972.

ABSTRACT

The technique for picture coding by first dividing the picture into subpictures and then performing a linear transformation on each subpicture and quantizing the resulting coefficients is discussed. Various transformations and quantization strategies are discussed. A summary of the dependence on the basic system parameters and some conclusions are presented.

13. Title: A Bound on the Rate Distortion Function and Application to Images
Author(s): P. A. Wintz and M. Tasto
Where Appeared: IEEE Trans. on Information Theory, Vol. IT-18, January 1972.

ABSTRACT

An upper bound on the rate distortion function for discrete, ergodic sources with memory is developed by partitioning the source sample space subset. The bound depends only on the mean vectors and covariance matrices for the subsets and is easy to compute. It is tighter than the Gaussian bound for sources that exhibit clustering of either the values or covariances of successive source outputs. The bound is evaluated for a certain class of pictorial data using both one-dimensional and two-dimensional blocks of picture elements. Two-dimensional blocks yield a tighter bound than one-dimensional blocks; both result in a significantly tighter bound than the Gaussian bound.

14. Title: Image Coding by Adaptive Block Quantization
Author(s): P. A. Wintz and M. Tasto
Where Appeared: IEEE Trans. on Communication Technology, Vol. COM-19, No. 6, December 1971.

ABSTRACT

A new source encoder called the adaptive block quantizer is proposed for coding data sources that emit a sequence of correlated real numbers with known first- and second-order statistics. Blocks of source output symbols are first classified and then block quantized in a manner that depends on their classification. The system is optimized relative to both the mean square error and the subjective quality of the reconstructed data for a certain class of pictorial data, and the resulting system performance demonstrated. Some interesting relationships between mean square error and subjective picture quality are presented.

15. Title: On the Effect of Timing Errors in Run Length Codes
Author(s): P. A. Wintz and L. C. Wilkins
Where Appeared: (Submitted for Publication), August 1971.

ABSTRACT

Many redundancy removal algorithms employ some sort of run length code. Blocks of timing words are coded with synchronization words inserted between blocks. The probability of incorrectly reconstructing a sample because of a channel error in the timing data is a monotonically non-decreasing function of time since the last synchronization word.

In this paper we compute the "probability that the accumulated magnitude of timing errors equal zero" as a function of time since the last synchronization word for a zero order predictor. The result is valid for any data source that can be modeled by a first order Markov chain and any digital channel that can be modeled by a channel transition matrix. An example is presented.

16. Title: Picture Bandwidth Reduction for Noisy Channels
Author(s): P. A. Wintz and C. W. Proctor
Where Appeared: TR-EE 71-30, School of Electrical Engineering, Purdue University, West Lafayette, Indiana, August 1971.

ABSTRACT

A system which utilizes linear transformation and block quantization to reduce picture bandwidth is described. Several computationally simpler systems are derived from this one. Rates as low as 1.4 bits/pel are achieved by the more complex system. The characteristics of these systems for transmission over noisy channels are investigated.

An algorithm for decomposing a picture into contours is described. The performance of this system used as a bandwidth reduction system for transmission over noisy channels is investigated.

17. Title: Automated Techniques for Data Analysis and Transmission
Author(s): P. A. Wintz and J. L. Gattis
Where Appeared: TR-EE 71-37, School of Electrical Engineering, Purdue University, West Lafayette, Indiana, August 1971.

ABSTRACT

This report describes a method for reducing the data needed to encode a quantized 2-dimensional array by utilizing its area properties. The data compression procedure was tested on a wide class of pictorial data. A modified procedure was used to obtain important area-related statistics of pictorial data.

An existing algorithm which locates and traces all contours of equal grey level of any quantized 2-dimensional array was modified so as to improve its data compression capabilities. In particular, unnecessary contour data was identified and in many cases, eliminated. Also, the algorithm was modified to handle eight directions of trace instead of four and the resulting data compression capabilities were compared. Improved contour data encoding techniques were also developed, particularly for the contour directionals. The coding schemes were optimized for three test pictures and then evaluated over a broad class of pictorial data. The overall bit compression ratio was computed for all test pictures.

Modified versions at the contour trace algorithm were developed and used to compute important area statistics of several of the test pictures. Statistics that were gathered included: distribution of the number of areas with respect to grey level; distribution of the number of areas with respect to area size; distribution of area size with respect to grey level, etc. The visual and compression effects of several requantization schemes were also studied.

The contour tracing data compression scheme yields significant compression for some classes of data. The compressions achieved in the work described here ranged from 7.2 to one for binary-level schematic drawings to 1.5 for multi-level "busy". The statistical area analysis described illustrates the potential of the contour tracing algorithm as a data acquisition device.

18. Title: Properties of the Human Visual System as an Image Evaluator
Author(s): P. A. Wintz and W. C. Wilder
Where Appeared: Internal Publication

ABSTRACT

Relevant physiological and psychological studies are reviewed and summarized to provide an understanding of the human visual system as a black box which evaluates the output of pictorial data processing systems. Also, the results of subjective evaluations of both television pictures and photographs are reviewed. Finally, a working reference list for these areas is provided.

19. Title: Bibliography on Data Compression, Picture Properties, and Picture Coding
Author(s): P. A. Wintz and L. C. Wilkins
Where Appeared: IEEE Trans. on Information Theory, Vol. IT-17, No. 2, March 1971.

ABSTRACT

Published papers and reports dealing with data compression, picture properties and models, picture coding and transmission, image enhancement, and human visual information processing are listed.

20. Title: Image Coding by Linear Transformation and Block Quantization
Author(s): P. A. Wintz and A. Habibi
Where Appeared: IEEE Trans. on Communication Technology, Vol. COM-19, No. 1, February 1971.

ABSTRACT

The feasibility of coding two-dimensional data arrays by first performing a two-dimensional linear transformation on the data and then block quantizing the transformed data is investigated. The Fourier, Hadamard, and Karhunen-Loeve transformations are considered. Theoretical results for Markov data and experimental results for four pictures comparing these transform methods to the standard method of raster scanning, sampling, and pulse-count modulation code are presented.

21. Title: Optimum Linear Transformations for Encoding Two-Dimensional Data
Author(s): P. A. Wintz and A. Habibi
Where Appeared: Picture Bandwidth Compression, edited by T. S. Huang and O. J. Tretiak, Gordon and Breach, Inc., New York, N.Y. 1971.

ABSTRACT

Optimum (mean square error) linear transformation for transforming two-dimensional data arrays into one-dimensional data arrays is developed. For continuous data the development is analogous to the Karhunen-Loeve expansion for one-dimensional continuous data, and for discrete data the development is based on Hotelling's method of principal components. The performances of both methods are evaluated and compared to the performances of various other source encoding strategies for the two-dimensional gaussian process with autocorrelation function $R(x,x', y,y') = \exp(-\alpha|x-x'|-\beta|y-y')$. Performance comparisons are made on the basis of mean square error and rate distortion function.

22. Title: Contour Structure and the Transmission of Pictures
Author(s): P. A. Wintz and J. L. Gattis
Where Appeared: Proc. of the UMR-Mervin J. Kelly Communications Conference, Rollo, Missouri, October 1970.

ABSTRACT

An algorithm for locating and tracing all contours of equal grey level of any 2-dimensional data array has been developed. A second algorithm which reconstructs the original data array from the contour data has also been written. This contour tracing routine has three primary areas of application: (1) data transmission, (2) data analysis, and (3) feature extraction for pattern recognition. Its use as a data transmission device is considered in this report. Modifications of the contour trace algorithm are used to gather statistics on picture content. These statistics aid in the design of an efficient contour data transmission system. Systems being developed from this statistical study are presented in this report.

23. Title: Studies on Data Compression - Part I: Picture Coding by Contours
Author(s): P. A. Wintz and L. C. Wilkins
Where Appeared: TR-EE 70-17, School of Electrical Engineering, Purdue University, West Lafayette, Indiana, September 1970.

ABSTRACT

PART I

A method is presented for reducing the number of bits required to describe a quantized 2-dimensional data array by making use of its area properties. The technique is also useful for gathering statistics on area-related parameters and for data processing such as image enhancement. The operation of the technique is demonstrated on several photographs which have been appropriately sampled and quantized.

The algorithm locates and traces all contours - outer boundaries of areas having the same grey level - of any quantized 2-dimensional data array. For each contour, the system outputs the value and location of the initial point and the direction of travel from element to element as the contour is traced in the clockwise direction.

A reconstruction algorithm is described which perfectly reconstructs the original data array from the output described above.

Several modifications of the standard algorithm are described. Every data array is composed primarily of contours which fit together like pieces of a jigsaw puzzle. There are, of course, some other contours which are completely embedded within a single contour. The former contours are called exterior, the latter: interior. This classification is the basis for two modifications of the original algorithm. The modifications allow us to delete either directional information (shape), or position information of many contours and yet reconstruct the original array perfectly. Statistical coding techniques are applied to the contour tracer output, and performance comparisons are made for the various codes.

The Contour Tracing Algorithm is quite useful in gathering statistics on area-related parameters. Techniques are described for determining area size, the total number of points on and within a contour, and the number of points represented by a contour.

The concept of interior and exterior contours leads to very interesting results concerning the distribution of these types of contours in a typical picture. Several pictures were made with the short exterior contours turned white in order to clearly mark their positions. Similar pictures were created marking the location of short interior contours. The results of these studies indicate that the exterior contours typically

occur in areas which are the most important subjectively. This is clearly demonstrated by a sequence of pictures in which short interior contours were deleted with little or no perceptible degradation. Corresponding pictures in which exterior contour were removed yielded appreciable degradation.

The improved overall bit compression ratio for several pictures with interior contour deletions is presented with the accompanying photographs.

PART II

Most redundancy removal algorithms employ some sort of run length code. Blocks of timing words are coded with synchronization words inserted between blocks. The probability of incorrectly reconstructing a sample because of a channel error in the timing data is a monotonically non-decreasing function of time since the last synchronization word.

In this we compute the "probability that the accumulated magnitude of timing errors equal zero" as a function of time since the last synchronization word for a zero order predictor. The analysis is based in part on some results on Semi-Markov processes due to Pyke. The analysis is valid for a data compression system employing a floating aperture zero-order redundancy remover with a limit ℓ on the maximum run length. (This constraint results from practical coding considerations and greatly complicates the analysis). The data source is modeled by a first order Markov chain with any valid transition matrix, and the digital channel is modeled by a channel transition matrix.

This general analysis is then applied to a particular data compression system, in which both the data source and the channel are characterized by transition matrices having constant main diagonals. Results are obtained for several values of ρ (source correlation) and Δ (channel error). A family of five curves corresponding to run length constraints of 4,8,16,32, and 64 is plotted for each ρ,Δ pair. These curves enable the system designer to select the synchronization block length so as to maximize the compression ratio while maintaining the required data quality.

24. Title: Image Coding by Coding Contours
Author(s): P. A. Wintz and L. C. Wilkins
Where Appeared: Proceedings of the International Communications Conference, June 1970.

ABSTRACT

In this paper we present a new version of the contour coding technique that allows for "non-essential" contours to be deleted. That is, all

contours that are completely imbedded in other contours can be reconstructed without knowledge of the directionals. Hence, the number of bits required to code the image is reduced by this factor.

25. Title: Optimum Adaptive Reception for Binary Sequences
Author: P. A. Wintz
Where Appeared: IEEE Trans. on Aerospace and Electronic Systems, Vol. AES-6, No. 3, May 1970.

ABSTRACT

The a posteriori probability density function $p(0|X_1,X_2,\ldots,X_K)$, where the X_i, $i=1,2,\ldots,K$, represent K vector-valued observations statistically related to the random vector 0, appears in many applications of the methods of statistical inference to problems in pattern recognition and statistical communication theory. In this paper, it is shown that for equally likely binary sequences (M=2) of anticorrelated patterns for signals observed in additive Gaussian noise, a device that computes $p(0|X_1,X_2,\ldots X_K)$ can be synthesized from a correlator, a simple instantaneous nonlinearity, and a multiplier. These results are used to derive some equally simple structures for various optimum nonsupervised estimators, pattern recognition machines, and signal detectors.

26. Title: Fast Multipliers
Author(s): P. A. Wintz and A. Habibi
Where Appeared: IEEE Trans. on Computers, Vol. C-19, No. 2, pp. 153-157 (SN), February 1970.

ABSTRACT

A number of schemes for implementing a fast multiplier are presented and compared on the basis of speed, complexity, and cost. A parallel multiplier designed using the carry-save scheme and constructed from 74 series integrated circuits is described. This multiplier multiplies 10-bit by 12-bit binary numbers with a worst-case multiplication time of 520 ns. The cost of the integrated circuits was less than $500.

27. Title: Calculation of Fourier Transforms on Finite Abelian Groups
Author(s): P. A. Wintz and G. R. Apple
Where Appeared: IEEE Trans. on Information Theory, Vol. IT-16, No. 2, March 1970.

ABSTRACT

A recent paper by Crimmins et al. deals with minimization of mean-square error for group codes by the use of Fourier transforms on groups. In this correspondence a method for representing the groups in a form suitable for machine calculation is shown. An efficient method for calculating the Fourier transform of a group is also proposed and its relationship to the fast Fourier transform is shown. For groups of characteristic two, the calculation requires only N $\log_2$ N additive operations where N is the order of the group.

28. Title: Picture Bandwidth Compression by Adaptive Block Quantization
Author(s): P. A. Wintz and M. Tasto
Where Appeared: TR-EE 70-14, School of Electrical Engineering, Purdue University, West Lafayette, Indiana, July 1970.

ABSTRACT

An adaptive source encoding system that adapts to the local properties of the picture by treating areas having a large amount of detail differently from areas of low detail is investigated. A discrete picture consisting of a kxk array of picture elements is first divided into smaller blocks of n elements each, both one- and two-dimensional blocks are investigated. The blocks are considered as n-dimensional random vectors. The vector space Ω is partitioned by hypersurfaces into L n-dimensional subsets called categories. A fixed decision rule is used to classify each block as one of the L categories. Then, each block is processed with a linear transformation matrix which is the eigenvector matrix of the covariance matrix of that category. The resulting coefficients are quantized and coded using known tachniques. However, different bit assignments and quantizer parameters are used for each category. We call this principle adaptive block quantization.

Rate distortion theory is applied to find lower bounds of performance. Instead of deriving the actual rate distortion function of the source emitting picture blocks (which appears to be very difficult) we derive an

upper bound given in terms of the eigenvalues of the category covariance matrices and the category probabilities. This bound is compared to another bound given by the eigenvalues of the overall covariance matrix, and sufficient conditions for it to be tighter than the latter one are given. A partition of Ω is derived which minimizes the bound for given mean square error under some constraints. This partition is given by a decision rule and decision functions which resemble those known to minimize the recognition error of mixtures of gaussian random vectors.

The two bounds are calculated for several still pictures, for which the covariance matrices are estimated. The first bound is considerably smaller than the second indicating a potential for rate reduction by the adaptive system. Three categories were found to be both feasible and capable of good performance. One category represents low correlation areas (high detail), the other two high correlation areas (low detail), one darker than average and the other brighter than average. The adaptive block quantization system is shown to have finite optimum block size, as opposed to the nonadaptive system.

Several implementable adaptive block quantization systems using uniform quantizers and natural codes as well as Huffman variable length codes are investigated using still pictures as data. The processed pictures are reconstructed and displayed as photographs. Systems with mean square error optimized parameters and also subjective picture quality performances of the several systems are compared. The latter performance criterion is measured by subjective tests using many observers.

Suboptimum systems that are much less complex but perform almost as well as the optimum system are also developed.